THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

SOUTHERN RESEARCH INSTITUTE

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**PARAMETRIC EMISSIONS MONITORING SYSTEM**
APPLICATION:	**CONTINUOUS MONITORING OF GASEOUS EMISSIONS FROM LARGE NATURAL-GAS-FIRED INTERNAL COMBUSTION ENGINES**
TECHNOLOGY NAME:	**ANR Pipeline Parametric Emissions Monitoring System**
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The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV Program is to further environmental protection by substantially accelerating the acceptance and use of improved and cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the purchase, design, distribution, financing, permitting, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations, stakeholder groups that consist of buyers, vendor organizations, and permitters, and with the full participation of individual technology developers. The program evaluates the performance of technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests, collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated, and that the results are defensible.

The Greenhouse Gas (GHG) Technology Verification Center (the Center), one of 12 technology areas under the ETV program, is operated by Southern Research Institute, in cooperation with EPA's National Risk Management Research Laboratory. The Center has recently evaluated the performance of the parametric emissions monitoring system (PEMS) for gaseous emissions from large natural-gas-fired internal combustion engines. This verification statement provides a summary of the test results for the PEMS, which is offered by the ANR Pipeline Company (ANR) of Detroit, Michigan.

TECHNOLOGY DESCRIPTION

The patented PEMS approach provides an alternative to instrumental continuous emissions monitoring systems (CEMS) and is potentially more cost-effective. The PEMS contains relationships between engine operating parameters, as determined by existing engine sensors, and exhaust emissions. As such, they are fundamentally computerized algorithms that describe emission rates without the use of significant new hardware. The parametric approach to determining air emissions is provided for in 40CFR64, and with over 13,000 natural gas compressors operating in the United States alone, the potential applicability of this system is significant.

In addition to monitoring emissions of carbon dioxide (CO_2), carbon monoxide (CO), total hydrocarbons (THCs), oxygen (O_2), and nitrogen oxides (NO_x), the ANR PEMS provides feedback on engine operating conditions that influence emissions. Different types of engines have unique operating characteristics, so there are unique relationships between emissions and operating parameters for each engine type. Therefore, the PEMS must be specifically calibrated for the engine type on which it will be used by operating the engine under a range of normal and off-normal operating conditions while simultaneously measuring emissions. This process is referred to as "mapping" the PEMS and was completed by ANR prior to the start of the test. The test engine was an Ingersoll-Rand (Model KVR-616), 16 cylinder, 6000 horsepower reciprocating engine.

The primary PEMS emission relationships are a function of engine speed and load (as torque). Additional operational parameters are also used by the PEMS to determine emissions. These include engine efficiency, ignition timing, and combustion air manifold temperature and pressure. On the test engine, efficiency is defined as the ratio between calculated fuel consumption and actual fuel consumption measured using a flow meter. Engine speed and torque values are used to define the "baseline" emissions profile for the engine. This baseline is representative of a normally functioning and well-tuned engine. As engine operational changes occur, indicators of engine efficiency, ignition timing, air manifold temperature, and air manifold pressure are used to adjust predicted emission values either upward or downward from the baseline level.

The ANR PEMS provides several different functions including the prediction of continuous emissions, the reporting of total emissions and high emission alarms/alerts, the monitoring of engine sensor performance, and the reporting of potential sensor malfunctions. ANR has found that combustion air temperature and combustion air pressure are two engine operating parameters that greatly affect emissions. Therefore, the ANR PEMS uses redundant engine monitoring sensors for these parameters. This redundancy provides for assessment of sensor drift and identification of failed or malfunctioning sensors.

VERIFICATION DESCRIPTION

The verification focused on the PEMS ability to accurately predict pollutant emissions under normal and off-normal engine operating conditions. Verification goals and parameters were developed to evaluate the PEMS over a full range of engine operating conditions. The verification parameters include the following:

- **PEMS relative accuracy (RA):** This parameter represents the accuracy of PEMS emissions predictions compared to EPA reference methods for $NO_{X,}$, CO, CO_2, and THCs.

- **PEMS accuracy during off-normal engine operation:** This parameter represents the PEMS prediction accuracy while physically perturbing combustion air manifold temperature and pressure, engine efficiency, and ignition timing.

- **PEMS ability to respond to sensor failure:** This assessment examines the PEMS ability to predict emissions when one or more of the engine sensors has failed or is responding incorrectly.

- **PEMS diagnostic capabilities:** Using data collected in support of the three verification parameters listed above, this assessment examines the value of the PEMS in alerting engine operators to operating conditions which could produce excess emissions or other engine problems.

These parameters were assessed through collection and analysis of emissions data generated by the PEMS, comparative EPA reference method gas measurements, engine data logs, and ANR-supplied data on engine operations. EPA Performance Specification Test procedures (40 CFR Part 60, Appendix B) were used to determine the relative accuracy of the PEMS with respect to emission prediction capabilities for NO_x, CO, THCs, and CO_2. As required by the Performance Specifications, EPA Reference Methods were used to measure actual pollutant concentrations and emission rates for comparison with the PEMS predictions. A total of 12 test runs, each 21 minutes in duration, were conducted in order to determine RA for each pollutant. Because engine speed and torque are primary determinants of engine emissions, the tests were conducted while operating at four different speeds and torque conditions within the normal operating range of the test engine. These operating regimes included 83 percent torque at 280 rpm, 82 percent torque at 350 rpm, 93 percent torque at 280 rpm, and 93 percent torque at 343 rpm.

To evaluate the PEMS ability to respond to off-normal engine operations, a series of tests were conducted while physically perturbing several key engine operating characteristics. The perturbations resulted in a complex reaction between the engine control system and engine, changing engine operations and emissions. The engine operating parameters having the most significant impact on PEMS emission predictions include air manifold pressure and temperature, exhaust manifold pressure and temperature, ignition timing, engine efficiency, and relative humidity. Exhaust manifold temperature and pressure could not be controlled in a predictable manner, and relative humidity could not be controlled or easily simulated. Therefore, the off-normal testing included physical perturbations to air manifold temperature and pressure, ignition timing, and engine efficiency. Emission changes occurring as a result of changes in the operating parameters may vary in significance depending on engine torque and speed settings. Recognizing this, perturbations were conducted at three different torque and speed operating regimes. This resulted in a total of 24 individual test runs during off-normal engine operations.

To evaluate the PEMS ability to respond to sensor failure or drift, another series of tests were conducted which included simulating failure or drift in engine sensors that are important to PEMS functions. The sensors adjusted during this series of tests included ignition timing, engine efficiency (fuel flow sensor), air manifold temperature, and air manifold pressure. Sensor failure/drift was simulated by intercepting the sensor output signals received by the PEMS and electronically adjusting the signals using the control-inhibit mode built into the engine operating software. Sensors were adjusted both above and below the reading received during testing to simulate sensor drift in either direction.

Separate test runs were conducted for each sensor while simulating sensor drift both above and below normal levels. This resulted in a series of eight single-sensor drift test runs (four sensors perturbed in two different directions). In order to assess the impact of multiple failed sensors, this entire procedure was then repeated for pairs of simulated sensor failures. These sensor perturbations were conducted for all combinations of pairing of the four sensor types used on the engine.

VERIFICATION OF PERFORMANCE

The RA testing conducted on the PEMS resulted in the following conclusions:

- The PEMS RAs for NO_x, CO, and CO_2 were 11.1, 3.9, and 6.8 percent, respectively, all well within the 20 percent acceptance criterion that would apply to conventional continuous emissions monitoring systems (CEMS) used in regulatory compliance service.

- The RA for THC was 34.2 percent. The difference between measured and predicted THC emissions are consistent with, and likely related to, an offset of 34 percent observed between the testing contractor's sampling system used for engine mapping, and the verification testing team's sampling system.

- Based on a qualitative assessment, the PEMS reliably predicts variations in NO_x emissions during normal engine operations.

During the off-normal engine operation tests, the engine was driven to off-normal operation until PEMS alert(s)/alarm(s) occurred to notify the operator. The engine was then further perturbed and the following observations were made:

- PEMS predictions of CO and CO_2 emissions were within approximately 15 and 5 percent, respectively, of the reference method values during off-normal engine operation.

- PEMS predictions of NO_x emissions were within 20 percent of the reference method data on 18 of the 24 tests conducted with the exception of two tests at low air manifold pressure, two tests with high ignition timing, and two tests where engine efficiency was perturbed.

- Similar to the RA tests, PEMS predictions of THCs were generally 20 to 30 percent higher than measured emissions and likely related to the mapping contractor offset previously mentioned.

The following summarize the findings of the sensor drift simulation tests where sensor output signals were altered to the alert or alarm level, and then further altered to simulate failure:

- The single sensor drift simulations had little or no impact on actual emissions other than NO_x. NO_x predictions during the perturbations were erratic as detailed in the report.

- PEMS predictions were representative of measured CO and CO_2 concentrations during all the tests.

- Consistent with the other tests conducted, PEMS predictions of THCs were generally 20 to 30 percent higher than measured emissions.

- Where redundant sensors were tested, the PEMS defaulted to the sensor that predicts NO_x emissions conservatively, as specified by ANR in the PEMS design.

With regard to PEMS diagnostic capability, the PEMS contains comprehensive alarm/alert functions that do provide diagnostic capability. At the test site, as at many compressor stations, engine sensor alerts and alarms may already be implemented in the station control system and, in such cases, the PEMS may not provide additional engine sensor alarm/alert capability. However, the use of redundant sensors by the PEMS does enhance diagnostic capability over what would otherwise be available because it allows the operator to quickly determine if an alarm is the result of a failed sensor or an engine malfunction. In addition, the PEMS provides a capability to readily assess and track changes in engine operations in terms of emissions.

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